Applied Mathematics & Information Sciences
*An International Journal*

http://dx.doi.org/10.12785/amis/090348

# Development of The Multi-Level Fusion based Security System

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Received: 18 Aug. 2014, Revised: 19 Nov. 2014, Accepted: 20 Nov. 2014
Published online: 1 May 2015

**Abstract:** The article develops the multi-level fusion based intelligent security system to be applied in home automation. The system contains some detection modules, a supervised computer, an elevator and an experimental platform. The detection modules have active detection modules and passive detection modules that are designed in our research team. The control unit of all detection modules (active and passive) is HOLTEK microchip. Mobile robots are active detection modules, and are classified more and more teams according to the detection functions. Each mobile robot of the team robot system transmits the real-time event signals to the supervised computer and the other mobile robots via wireless RF interface, and moves to any floor of the experimental platform using the elevator. The passive detection modules contain wire/wireless detection modules. If the event occurrence, the passive detection modules can decide the event to be true or false in the level one using weighted average algorithm, and transmits the position of the event to the supervised computer and mobile robots. Mobile robots can detect the event to be true or false using Dempster-Shafter (D-S) evidence theory, and transmits the relation location of the event to the supervised computer, too. The supervised computer decides the event to be true according to the feedback signals using D-S evidence theory, and controls the other mobile robots moving to the event location for double check, and recognizes the final decision output using D-S evidence theory in the level two. Finally, we present some experimental results using the active and passive detection modules to detect the fire source on the experimental platform

**Keywords:** home automation, HOLTEK microchip, wireless RF interface, weighted average algorithm, Dempster- Shafter evidence theory

## 1 Introduction

Intelligent buildings and home can provide safety, convenience and welfare for human living in the 21st century. The most important issue of the intelligent building is security system. In generally, the security system contains supervised system, remote supervised system, active and passive detection modules and appliance control modules, and uses redundant and complementally information fusion algorithms to enhance system reliability and certainty, and constructs the safety detection network using multiple processing protections. The multi-level security system solves the negligence of the users. Each level complements enough the disadvantages of the other levels. The paper proposes the multi-level security system that contains multiple medium based detection modules, and multiple team-robot systems.

In the past literatures, many experts research in the security system. Azegami and Fujiyoshi [1] described a systematic approach to intelligent building design. Kujuro and Yasuda [2] discussed the systems evolution in intelligent building. Chung and Fu expected to set up the standard of appliances and communication protocols, and proposed a complete system architecture with integrate control kernel to construct an intelligent building [3].

Mobile robots are main roles of the active detection modules in the security system. Recently more and more researchers take interest in the field especially intelligent service robot. Yoichi Shimosasa et al. developed autonomous guard robot [4] which integrated the security and service system. There are more merits in the mobile robots to use team robot cooperation capabilities to such a large fleet of robots. In general, the control structure of the large fleet team mobile robots is classified centralized control and decentralized control. A centralized control

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requires robust and permanent communication capabilities between all the robots and supervised system. A decentralized control only requires local communication between robots and supervised system [7]. The paper develops some team-robot systems to combine the centralized control and decentralized control, and operates with the passive detection modules to be applied in the security system of the intelligent home.

## 2 System Architecture

The system architecture of intelligent home is shown in Figure 1. The system contains passive detection modules, active detection modules and some system supervised devices [5]. The passive detection modules contain wire/wireless detection modules. The wire based detection modules communicate with the supervised computer via wire RS485 interface. The wireless based detection modules communicate with the supervised computer and mobile robots via wireless RF interface. The supervised computer receives detection signals from active detection modules and passive detection modules via wireless RF interface, and uses weighted average algorithm and D-S evidence theory to decide the event to be true or not on multi-level detection structure. The active detection modules include multiple team-robot systems. Mobile robots of each team-robot system carry the same sensor to detect the dangerous event of intelligent home. Multiple team-robot systems use variety sensors to detect variety events. The other mobile robots of the team-robot system receive the event signals from the supervised computer or the same function based passive detection modules, and moves to the event location doing double check. The detection algorithm is D-S evidence theory. All detection modules of the intelligent security system have been finished, and are arranged in the experimental platform of the intelligent home to be shown in Figure 2. The experimental platform has three floors. Each floor contains three rooms to be assigned variety detection modules. Mobile robots of each team-robot system move on any floor of the experimental platform to detect event using the elevator. The elevator uses many IR transmitters to guard the mobile robots moving into the elevator, and communicates with mobile robots via wireless RF interface.

The detection processing of the security system is classified two levels to be shown in Figure 3. We use passive detection modules and mobile robots around the event location to make a decision using weighted average algorithm and D-S evidence theory. These detection modules transmit the event signals to the supervised computer via wire RS485 interface or wireless RF interface. We call the processing schedule to be level one. Then the supervised computer has received these detection signals to make a decision using D-S evidence theory, and controls the other mobile robots of the same

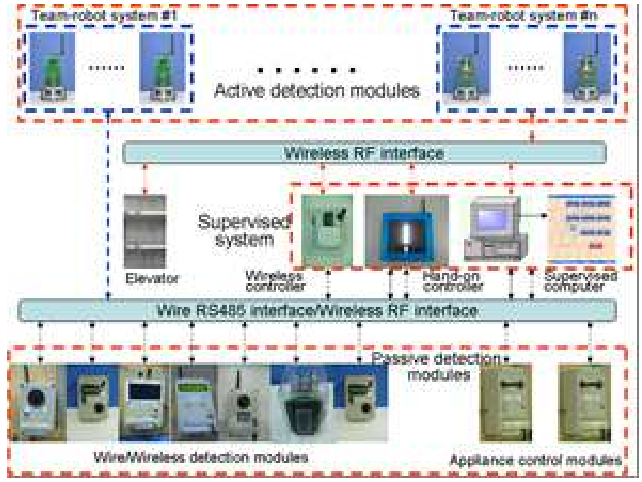



**Fig. 1:** System architecture


**Fig. 2:** Experimental platform of the security system

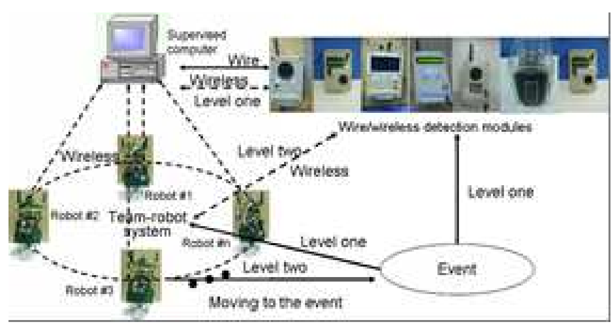



**Fig. 3:** The detection processing of the event happened

**Table 1:** The communication protocol

| Byte number | 0 | 1-8 | 9 |
|---|---|---|---|
| Definition | Start byte | Data bytes (ID, sensor, command, robot, data) | Check sum |

**Table 2:** The feedback data of the wire/wireless fire detection modules

| | | | | |
|---|---|---|---|---|
| Byte number | 1 | 2 | 3 | 4 |
| Definition | ID code | sensor kind | Module number | No use |
| 5 | 6 | 7 | 8 | 9 |
| Measurem-ent value | Measurem-ent value | Measurem-ent value | Measurem-ent value | Check sum |

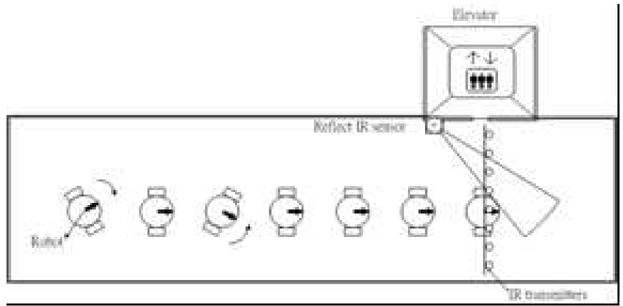



**Fig. 4:** The guard schedule of the mobile robot

team-robot system to do double check. The security system decides final result of the event. The processing schedule is level two.

We arrange an ID code in each active detection modules and passive detection modules, and identify the functions. The communication protocol between the supervised computer and passive detection modules is ten bytes to be listed in Table 1. We explain the feedback data of the fire detection modules. The protocol of the wire module and the wireless module is the same arrangement. There are one start byte, eight data bytes and one check sum byte. The start byte trigs the wireless RF module to receive the signals from the transmitter. The data bytes contain ID code (one byte), sensor kind (one byte), module number (1 byte), and measurement values (four bytes). The ID code decides the transmitting direction between of the supervised computer and detection modules. The sensor kind selects the attribution of carried sensors. The communication protocol of the feedback data from the detection modules is listed in Table 2. The measurement values of the passive detection modules are from byte 5 to byte 8. The supervised computer receives the event signal from the event location, and program the processing flowchart to deal with the dangerous status.

## 3 Detection Module

The detection modules of intelligent home are classified two types. One is active detection modules; the other is passive detection modules. We explain the functions of these detection modules as following:

### *3.1 Active detection modules*

The main role of the active detection modules is the mobile robot. The mobile robot has the shape of cylinder, and its equipped with a microchip (HT46RU25) as controller, and calculates the movement displacement using encoder of the DC servomotor moving on the experimental platform. The reflective IR sensors of the mobile robot detect obstacles. The mobile robot uses the compass module to compute the orientation, and uses IR receiver to locate the position of the elevator. The control structure of each team-robot system uses multilevel control structure to combine the merits of centralized control and decentralized control. The mobile robot can communicates with the others of the team robot system and the supervised computer via wireless RF interface, and knows the location of each mobile robot. The mobile robot moves on the experimental platform, and knows the relation distance far from the elevator according to the IR transmitters. The IR transmitters are embedded on the roof of the experimental platform, and guard the mobile robot moving to the elevator to be shown in Figure 4. The reflect IR sensors of the elevator is arranged on the door, and detects the mobile robot that has been moving into the door of the elevator.

### *3.2 Passive detection modules*

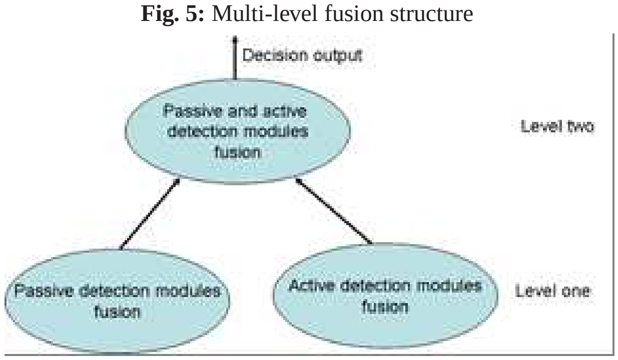
We develop passive detection modules and appliance control modules of the intelligent security system using multi-models fusion architecture. The passive detection modules contain fire detection module, intruder detection module, environment detection module, gas leakage detection module, power detection module, and gas detection module. The passive detection modules extend up to $2^{16}$ pieces, and are classified sensor kind and module number to be programmed in Table 2. The sensory kinds and detection algorithms of the passive detection modules are listed in Table 3.

In the paper, we use wire/wireless fire detection modules to detect fire source. The decision center of the module is a HOLTEK microprocessor to perform computation of improved weighted average algorithm. In general, these sensory signals are tiny voltage output. We must process these signals to convert to standardize voltage output $(0V \sim +10V)$by amplifier circuit. The relations of input sensory signals and output voltage signals must be linear by tuning the processing circuits.

**Table 3:** Sensors and detection algorithms of the passive detection modules

| Module | Sensors | Fusion algorithms |
|---|---|---|
| Fire detection module | Three flame sensors. | Weighted average algorithm |
| Intruder detection module | Magnetic sensor, IR sensor or body sensor. | Voting method |
| Environment detection module | humidity sensor, illumination sensor and temperature sensor | No |
| Power detection module | Four current sensors (AC type). | Redundant management method |
| Gas leakage detection module | Two gas sensors | Weighted average algorithm |
| Gas detection module | Smoke sensor, nature gas sensor, LPG sensor, airpollution sensors, ammonia sensor, alcohol sensor and carbon monoxide sensor | Bayesian theorem |

**Fig. 5:** Multi-level fusion structure




But the flame sensor must be driven by 350V. We use the high-voltage converter circuit to convert oscillate signal $(\mathrm{Vp}=5\mathrm{V})$ to high voltage oscillate signal output $(\mathrm{Vp}=350\mathrm{V})$. The output signal of the module is 1 to detect fire source; otherwise the output signal is 0.

## 4 Algorithms Analysis

In the paper, we use fire based team-robot system, wire fire detection module and wireless fire detection module to detect fire source, and use two-level multisensor fusion scheme to decide the fire event to be true or false. The fusion structure of the security system is shown in Figure 5. In the level one, we use weighted average algorithm to be applied in the passive detection modules, and use D-S evidence theory to be applied in the active detection modules.

In the level two, the supervised computer receives the detection results from the level one, and decides the event to be true using D-S evidence theory. The supervised computer can controls the other mobile robot moving to event location, and makes the final decision using D-S evidence theory. We use weighted average algorithm to detect fire event in the level one, and use $n$ passive detection modules to detect fire event. First the measurement value of the $ith$ detection module is $x_i$ with weights $0 \le \omega_i \le 1$ is

$$\bar{x} = \sum_{i=1}^{n} \omega_i x_i \tag{1}$$

$$\sum_{i=1}^{n} \omega_i = 1 \tag{2}$$

The weights can be used to account for the differences in accuracy between the wire detection modules and the wireless detection modules. In the fire event detection module, we set the same weight values for these modules, and calculate the average value $\bar{x}$ to be over than threshold. We can say the fire event to be true. Otherwise we can say no fire condition.

D-S evidence theory is a two-value uncertainty mapping, upper and lower uncertainty measurement, between two spaces. The evidence theory is an extension to the Bayesian approach that makes explicit any lack of information concerning a propositions probability by separating belief for the proposition from just its plausibility. A brief overview of the D-S evidence theory is provided as follows. Let $\varphi$ is empty set, and $\theta$ represents the set of hypotheses. The set of propositions $\{A_j \,|A_j \in 2^{\theta}\}$ for which a sensor is able to provide direct information are called focal element. For each sensor $S_i$, the function

$$m_i : \left\{A_j \,|A_j \ \in 2^{\theta}\right\} \to [0,1] \tag{3}$$

From this basic belief assignment $m$, a "belief" or "support" function is defined for $S_i$ as

$$bel_i(A) = \sum_{A_j \subseteq A} m_j(A_j) \tag{4}$$

In a similar manner, "doubt" function, "plausibility" function, and "uncertainty" function are defined as [6]

$$dbt_i(A) = bel_i\left(A^c\right) \tag{5}$$

$$pls_i(A) = 1 - dbt_i\left(A\right) \tag{6}$$

$$u_i(A) = pls_i\left(A\right) - bel_i\left(A\right) \tag{7}$$

The interval $[bel\,(A)\,, pls\,(A)]$ is termed a belief interval and represents. "Dempsters rule of combination" is used to fuse the proposition $X$ and $Y$ from the two sensors $S_i$ and $S_j$

$$m_{i,j}(A) = \frac{\sum\limits_{X \cap Y = A} m_i\left(X\right) m_j\left(Y\right)}{1 - \sum\limits_{X \cap Y = \varphi} m_i\left(X\right) m_j\left(Y\right)} \tag{8}$$

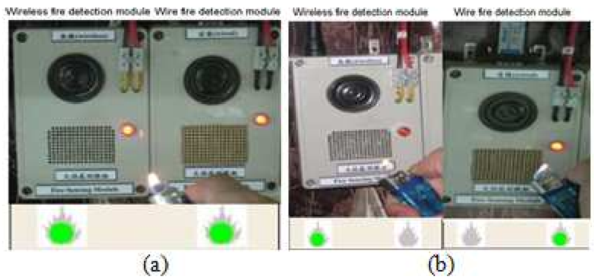



**Fig. 6:** The fire detection using passive detection modules

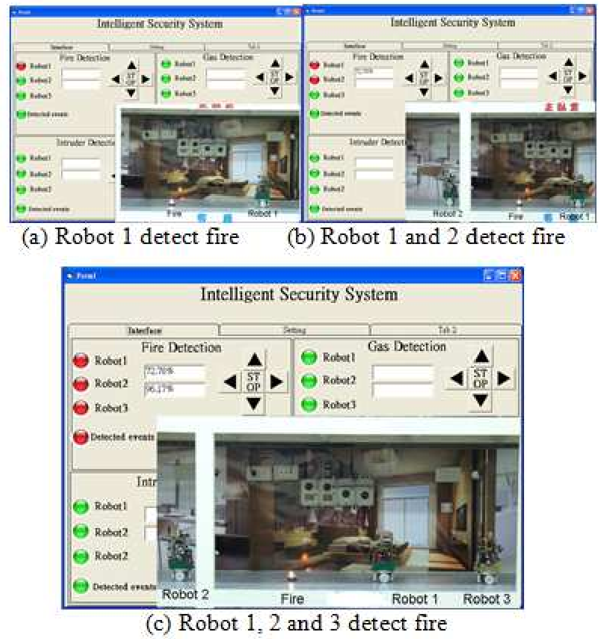



**Fig. 7:** The fire detection using active detection modules

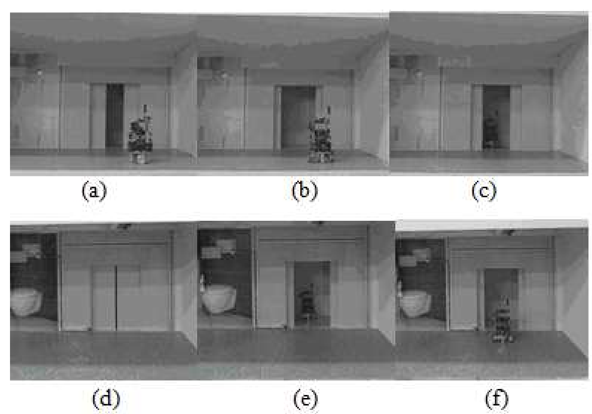



**Fig. 8:** The mobile robot moves to the elevator

## 5 Experimental Results

In the intelligent security system, we use wire fire detection module and wireless fire detection module and the fire based team-robot system to detect the fire source on the experimental platform. We use one lighter to provide fire source on the wire and wireless fire detection modules, and test the function of the modules to be right respectively. The detection modules can transmit the detection signals to the supervised computer via wire RS485 and wireless RF interface. The label of the fire detection modules displays green on the user interface to be shown in Figure 6(a). We provide the fire source to the two fire detection modules to test cooperation working. The supervised computer can decides the event to be true using weighted average algorithm in the level one. The experimental result is shown in the bottom of Figure 6 (b).

Then the mobile robots of the fire based team-robot system with flame sensor moves to the event location. The mobile robot 1 detects the fire event (candle), and transmits the event signal to the supervised computer to be shown in Figure 7 (a). The mobile robot 2 moves to the event location, and transmits the detection signal to the supervised computer, too. The supervised computer receives the event signal to calculate the belief value using D-S evidence theory. The belief value (0.7278) is not over the threshold value (0.800) to be shown in Figure 7 (b). The detection processing is level one, too. Users can set the threshold value on the user interface of the supervised computer before the test.

The mobile robot 3 of the fire based team-robot system detects the fire source on the platform, too. The supervised computer uses D-S evidence theory to calculate belief value is 0.9617 to be bigger than the threshold. The label of the detection event is red to be shown in Figure 7(c). We set the probability values to be the same for each flame sensor of the mobile robots. Finally we make a decision to be true for the fire event in the level one.

The supervised computer controls the other mobile robot of the fire based team-robot system moving to the fire location for double check in the level two. Now the fire event is at the second floor. The mobile robot is at the first floor. The mobile robot receives the signals of the IR transmitters moving closed to the elevator at the first floor, and communicates with the elevator via wireless RF interface. The mobile robot orders command to open the door of the elevator, and moves into the elevator. The elevator carries the mobile robot going up to the second floor, and opens the door. The mobile robot leaves the elevator moving to the fire location to be shown in Figure 8.

In the level two, the supervised computer has received the signals from the passive fire detection modules to be shown in Figure 9(a). We use red label to present the

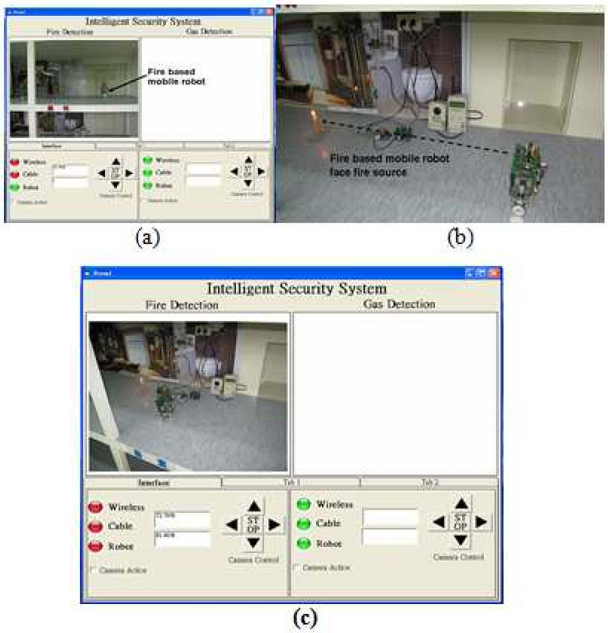



**Fig. 9:** The fire detection using passive and active modules

event to be true. Then the mobile robot of the fire based team-robot system moves to the fire location, and detects the fire event on the experimental platform, and transmits the event signal to the supervised computer, too. The experiment scenario is shown in Figure 9(b). Finally the supervised computer calculates the final decision using D-S evidence theory. The belief value is 0.9709 over the threshold value to be shown in Figure 9(c), and is bigger than the previous belief value (0.9617). We have more confidence to decide the fire event to be true.

## 6 Conclusion

We have presented a multi-level based security system to be applied in intelligent home. The controller of the active and passive detection modules is HOLTEK microchip. We use weighted average algorithm and D-S evidence theory to enhance the detection accuracy, and implemented the proposed algorithms in the supervised computer. We use fire event to implement the function of the multi-level based security system, and present experimental scenario on the experimental platform. The supervised computer makes double check the event occurrence. In the future, we want to integrate more and more passive detection modules, and cooperate with the multiple team-robot systems, and develop new user interface and remote supervised system to connect with the security system via Internet.

## Acknowledgements

This work was supported by National Science Council of Taiwan (NSC100-2221-E-224- 018).

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